AUTOMATIC FLOW CONTROL FOR AERIAL APPLICATIONS

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ABSTRACT. *Two versions of the automatic flow control system for aerial application, marketed by Auto Control, Inc. of Houma, Louisiana, were evaluated by using test protocols that included area applications with a range of application rates. Both units were effective in maintaining accurate control of flowrate while making aerial applications. The primary difference between the two controllers was that the AutoCal I controlled flow directly by adjusting the boom valve and the AutoCal II controlled the flowrate indirectly by adjusting a bypass valve located between the pump outlet and inlet. The AutoCal I had a maximum error of 1.55% while applying 37.4 L/ha (4 gal/acre) under controlled conditions. Experimental error was not significantly affected by application rate in either system. Theoretical error, expressed as the area between the required flowrate and actual flowrate curves, tended to increase with the number of spray runs used to spray a field. Theoretical error was 0.79% for five spray passes and increased to 3.2% for 20 spray passes. Experimental errors for the AutoCal II flow controller varied from 0.64 to 1.60% while making applications using rates that ranged from 9.4 to 88.9 L/ha (1 to 9.5 gal/acre). Controller response was evaluated by using the decay of cumulative remaining error for each spray run. The resulting time constants indicated that the controllers reduced remaining error to less than 37% of its initial value in less than 0.5 s.*

Keywords. *Aerial application, Automatic control, Ground speed, Global Positioning System.*

Ground–speed variability is a source of uncontrolled application error when spray planes are not equipped with automatic flow controllers. The use of flow controllers, to maintain correct flowrate to the boom as ground speed changes, eliminates most of this error. Normally, spray planes are calibrated to deliver a specific application rate when operated with a specified combination of ground speed and boom pressure. Boom pressure in a typical aerial spray system is set by adjusting the position of the boom–valve–handle stop. This mechanical stop limits the travel of the boom–valve handle and thereby limits the opening of the boom–valve. The boom valve is designed so that when the valve is partially open, some of the liquid coming into the valve is diverted through a bypass port, back to the hopper containing the spray mix. The proper setting is achieved when the plane is traveling at the calibration ground speed and the boom pressure is adjusted to the calibration pressure. Flying aerial application planes at high speeds near the ground does not permit adjustments of spray pressure or engine power during a spray run; therefore, if wind speed or wind direction changes from that experienced during the calibration process, the actual application rate will change accordingly.

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Factors that affect application accuracy include airspeed, ground speed, and swath alignment. Depending on many conditions, the power of the plane can be set to achieve a nominal air speed. The aerial spray–system pump is propeller driven; therefore, anything that changes airspeed of the plane has an effect on the pump delivery. Ground speed of the plane varies considerably due to the wind. With no wind, ground speed equals air speed, but wind in the direction of flight either reduces or increases the ground speed. If a plane has an air speed of 217 km/h (135 mph) and experiences a headwind of 16 km/h (10 mph), the plane's upwind ground speed would be to 201 km/h (125 mph), and its downwind ground speed would be 233 km/h (145 mph). This difference in ground speed would cause a 14.8% difference in application rate between sprays in opposite directions. Swath alignment on modern spray planes is achieved by GPS (Global Positioning System) based guidance systems that provide guidance to the pilot to prevent overlaps or skips in the application. Therefore, error in swath alignment does not play as large a role in application error as deviations from the calibration ground speed and pressure. The dynamic nature of the aerial spray–system operating environment precludes the use of a single setting for making accurate applications during each swath of a spray job. Therefore, the use of an automatic flow control system is needed that responds to changing conditions as the spray job proceeds.

Current application rate recommendations for crop protection materials have been developed and tested to provide pest control for a range of environmental conditions and application methods. These recommendations assume a uniform (consistent) application across the field. Prior research has shown that the use of reduced–rate applications of herbicide can provide weed control equal to the use of full–rate applications (Steckel et al., 1990). Without flow control, full–rate aerial applications (made parallel to the wind direction) result in reduced–rate applications on 50% of the field and over–rate applications on the rest of the field.

The use of automatic flow control provides a uniform application rate across the field and offers the possibility of reducing the rate of materials applied while maintaining the desired level of pest control.

With the advent of GPS–based swath–guidance systems, pilots have convenient access to ground speed displays. These guidance systems provide awareness of the ground speed value, but have no capability to respond to deviations from the calibration speed. Automatic flow controllers make corrections in the boom flowrate to compensate for ground speed changes so that all spray passes receive the same application rate.

Kirk and Tom (1996) evaluated the SATLOC automatic flow control system (SATLOC, Inc., Tempe, Ariz.) using continuous spray runs of 1600 m (1 mile). Performance was evaluated from data logged during the flight. These data described the performance of the controller relative to the information it received from the flow sensor and GPS receiver. It did not include actual error in water volume applied to the area sprayed. The evaluation included at least three spray runs upwind and three runs downwind for four different wind speed levels. Error in flow–controlled spray rate ranged from 0 to 4.4% and averaged 1.7% over the eight treatments. Without the flow controller, errors ranged from 6.4 to 14.3%.

Smith (1997) evaluated an early version of the AutoCal I automatic flow controller (Auto Control, Inc., Houma, La.) using a combination of logged flight data and measurements of actual water volume sprayed. Results from spraying 19 L/ha (2 gal/acre) on a 40–ha (100–acre) plot revealed that application error with the system operating was 0.48%. Without flow control, error was 7.25%. Average upwind speed during the application was 209 km/h (130 mph), and average downwind speed was 234 km/h (145 mph). Evaluation of performance over a range of application rates indicated that the calibration code and sensitivity values for this version of the controller needed to be adjusted for the application rate being applied.

FLOW CONTROLLERS

Auto Control, Inc. of Houma, Louisiana, currently markets two versions of their AutoCal flow controller: a) the AutoCal I that adjusts the boom–valve to control boom flow, and b) the AutoCal II that adjusts a bypass valve between the pump outlet and inlet to control boom flow.

The AutoCal I controls flow in a direct way by adjusting a valve in the flow path (figs. 1 and 2). The link connecting the boom handle and the 90°–pivot link directly below it was replaced with a servo–controlled linear–actuator that extended or retracted in response to commands from the control unit in the cockpit. With the boom–valve handle in the cockpit locked in the full–open position, actuator motion opened or closed the boom valve to control flowrate to the boom. The overall system consisted of the following: a control unit, a display, a GPS receiver, a servo driven linear actuator, a boom–valve, and a flow sensor. The control unit had provisions for setting application rate, swath width, calibration code, and sensitivity by using toggle switches. When the appropriate three–position switch (center off) was toggled up, the associated parameter value would increase. Likewise, when it was toggled down, the associated parameter value would decrease.

Two modes of use could be selected with a switch on the control unit: a calibration mode for performing calibrations and an operating mode for normal flowrate control. Calibration mode deactivated automatic control functions and made provision for calibrating the system by displaying flow meter output and activating calibration code setting functions. Operating mode activated the automatic control function and displayed the required flowrate, actual flowrate, servo position, ground speed, swath width, application rate, and system sensitivity.

Calibration consisted of determining the calibration code value to convert the flow meter output signal to actual flowrate passing through the meter. The system must be able to accurately interpret the flow meter output in order to

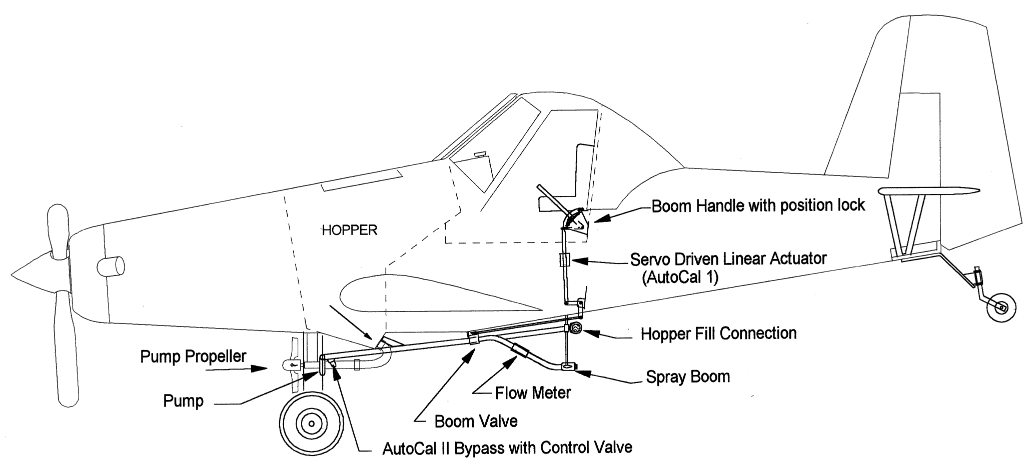

Figure 1. Essential components of an Air Tractor 402 spray system equipped with automatic flow control. The AutoCal I controlled flowrate to the boom by adjusting the boom valve. The AutoCal II controlled flowrate to the boom by bypassing some of the pump discharge back to the pump inlet.

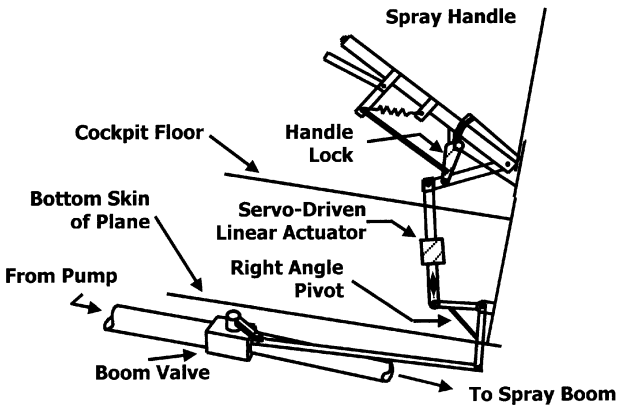

Figure 2. Control actuator for the AutoCal I was positioned in the linkage between the boom valve handle in the cockpit and the right angle pivot. Additional modifications to the boom handle for this version were the handle lock and the lock–release mechanism.

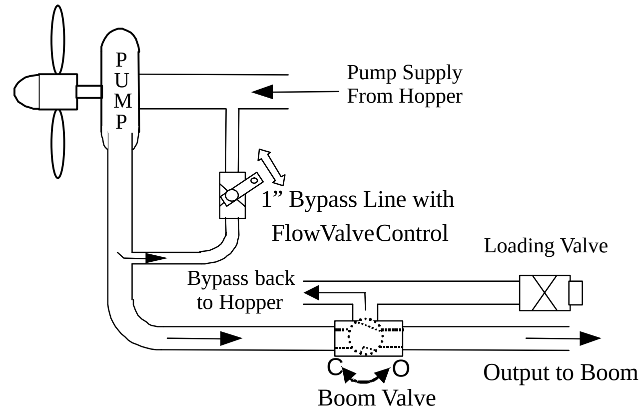

Figure 3. Schematic of bypass line and flow control valve for the AutoCal II flow control system as installed on an Air Tractor 402 and viewed from above. A cable (not shown) from a servo–driven linear–actuator mounted beneath the cockpit operated the flow control valve. The AutoCal ll used a different actuator from that used by AutoCal l.

function properly. Calibration was accomplished by pumping water through the flow meter at a known flowrate and adjusting the calibration code until the flowrate on the AutoCal display agreed with the known rate.

Automatic control of application rate was achieved by sensing the current ground speed of the aircraft, computing the flowrate required to achieve the specified application rate across the specified swath width while traveling at the current speed, and correcting actual flowrate to achieve the required application. Corrections were applied at a nominal frequency of 2 Hz.

The control algorithm was designed to initiate automatic control when the flow sensor output indicated that spray material was flowing to the boom. Between spray runs, the controller adjusted the boom valve to a half–open position. Therefore, when the pilot started the next spray run, initial valve adjustment to achieve control was normally no more than one fourth of the control range that extended from fully open to fully closed.

The AutoCal I system used the Crop Hawk flow sensor (Onboard Systems, Portland, Oreg.) to measure boom flowrate. The Crop Hawk flow monitor is a common accessory on spray planes and is used for monitoring flowrate to the boom and volume of spray in the hopper. This flow sensor (series 4100) had a flow range of 23 to 681 L/min (6 to 180 gal/min) with a linearity of ±1% and a repeatability of 0.05%. The Crop Hawk system was fully independent of the AutoCal I, but its flow sensor output provided flowrate information to the AutoCal I. Calibration was necessary in order for the AutoCal I to accurately interpret the flow sensor signal.

The AutoCal II was similar to the AutoCal I except that the boom valve was no longer used to control the application rate. The boom valve functioned as a manually operated ‘on/off’ spray valve on the AutoCal II. This version used a flow control valve located in a bypass line that was added to the spray system between the pump outlet and inlet (figs. 1 and 3). The 2.5 cm (1–in.) bypass line was connected to the 5 cm (2–in.) pump outlet; therefore, it could divert about 25% of the pump output. The system functioned by closing off the bypass valve to increase flow to the boom or by opening the bypass valve to reduce flow to the boom. This control technique required the pump delivery to be within the control range of the system. The pump had to deliver a flowrate sufficient to supply the desired application rate, but delivery could not exceed the application flowrate plus the maximum bypass flow that could occur with the bypass control valve fully open. For systems without an adjustable pump, excessive pump output could be diverted through the bypass port on the boom valve. The setup for best control response was achieved when the pump (or boom valve bypass) was adjusted to bring the control valve to a half open position while spraying at the calibrated ground speed. In this position the system was in the middle of its control range, and was capable of providing a symmetrical response to increased or decreased ground speeds. In addition to better response, another advantage of the half–open ‘control’ position was that the controller automatically adjusted the valve to this position between spray runs. Therefore, the valve only had to compensate for the difference between actual speed and calibration speed when spraying began.

A different flow meter was installed for use with the AutoCal II system. This sensor was the TM0150 model flow sensor manufactured by Turbines, Inc. of Altus, Oklahoma. It had a specified accuracy ±1.0% and repeatability of ±0.10% over the range of 57 to 681 L/min (15 to 180 gal/min). These specifications were similar to those of the Crop Hawk sensor and should not have made a significant difference in the function of the controller.

Objective

The objective of this work was to evaluate the performance of AutoCal automatic flow controllers while making multiple–pass aerial applications and provide the manufacturer with information useful for improving the control algorithms and hardware.

Methods

The performance of the flow controllers was tested by using two different approaches. Tests under controlled conditions were made to evaluate the ability of the controller to determine and apply the correct application rate without the dynamic influences normally experienced during aerial application. Multiple pass applications were used to evaluate the controller under conditions that incorporated variable speeds and different application rates. All tests were applied with the controllers installed on a turbine–powered Air Tractor 402. The aircraft was initially prepared at the beginning of each testing day by adding about 100 L (25 gal) of water to the hopper and filling the spray system plumbing by opening the boom valve and the valves on the ends of the booms. After water began flowing from the ends of the boom, the boom–valve and end–valves were closed, and the rest of the water was drained from the hopper through the fill–tube. The hopper was then ready to be loaded with the required volume of water for the test run (the amount to be sprayed plus about 76 L (20 gal)). The extra volume was included to avoid an empty hopper (and associated erratic system performance) at the end of the run. After spraying, the remainder of the load was drained from the hopper through the fill–tube and weighed on a balance. The volume sprayed could be determined by subtracting the volume drained from the hopper after the run from the amount loaded for the test.

The AutoCal system transmitted a data stream to a notebook computer mounted in the baggage compartment of the Air Tractor. The data stream content included application rate, swath width, calibration code, sensitivity, required flowrate, actual flowrate, ground speed, servo position, and status code. These data were logged to a file on the notebook computer and were useful in evaluating the performance of the controller.

The Air Tractor was also equipped with an Air–Star swath guidance system (SATLOC, Inc., Tempe, Ariz.) that provided guidance to the pilot while spraying and logged flight information to a user accessible log file. Logged data of interest for this study was collected at 1.0–s intervals and included ground speed, time, and spray activation flags. At the end of the test day, the logs were downloaded to a PC and converted to an ASCII text file. The Air–Star system also provided a display of accumulated spray–time and sprayed–area. These data were used to guide the pilot in performing the spray test and were useful in performance evaluation.

Initial tests on the AutoCal I were designed to evaluate the ability of the controller to apply water at a prescribed application rate while ground speed was maintained at a near constant value. The plane was loaded with the required volume of water as measured with a calibrated flow meter. The pilot then made two 45–s spray runs while maintaining a ground speed of approximately 217 km/h (135 mph) before returning to the loading area. The unsprayed water remaining in the hopper was then drained through the fill–tube and weighed to the nearest 45 g (0.1 lb). Experimental error was computed as the percent difference between the required volume for the run and the sprayed volume. For these tests, the required volume was computed from application rate, swath width, average ground speed, and spray time. The volume sprayed was computed as the difference between the volume loaded and the volume drained from the hopper at the completion of the test run. In order to evaluate the capability of the controller system without including error due to loading or recovery, a theoretical controller error was also computed. This theoretical controller error was based on data that the control system accessed as it controlled the application rate. Data records captured during the spray run included the required flowrate (computed from ground speed, swath width, and application rate) and actual flowrate as measured by the flow meter on the spray system. The area beneath the required and actual flowrate curves (plotted against time) was computed to convert the flowrate data to required and actual volumes for the spray run. The theoretical error was computed as the percent difference between theoretical ‘actual’ and ‘required’ spray volumes.

A Cumulative–Remainder (CR) error function was generated to visualize how quickly the controller was able to reduce error to a reasonable level. This function was defined as the cumulative error from any point in the spray run to the end of the run. For a spray run data set containing ‘n’ records and ‘(n – 1)’ error calculations, the function for the k’th point in the run could be described as shown in equation 1.

$$CR_k = \sum_{i=k}^{i=(n-1)} ERROR_i \quad (1)$$

$ERROR_i$ in equation 1 is the theoretical error associated with the i^{th} data interval (between records) in the captured data for a particular spray run. It was computed from flowrate versus time curves as the difference between the areas (under the curves) for the i^{th} interval associated with the “required” and “actual” flowrates. Theoretical error was greatest when the spray run was initiated because the control valve had to be adjusted from its mid–range (no spray) position to the required control position. Therefore, the first few terms of this function were similar to an exponential waveform (Thomas and Rosa, 1984) that had a specified amplitude at time equal to zero and began to decay exponentially to zero as time increased. Such waveforms are compared with a time–constant (TC), which is numerically defined as the time required for the amplitude to decay to 36.8% of its original value. In the CR function, the original amplitude was the total error for the run. Its value decreased throughout the spray run because of two factors. The number of intervals included in CR_i decreased, and error magnitude associated with each interval decreased as the control valve reached its control position. The value of the time constant showed how quickly the controller reduced remaining theoretical error to 36.8% of the original amplitude. It should be noted that the CR was computed as the algebraic sum of the errors associated with intervals between data records captured during the spray run; therefore, its initial value (i = 1) is equivalent to the total theoretical error that occurred for the spray run.

Dynamic performance of the AutoCal I was evaluated with a test that required the application of water on 23–ha (57–acre) plots with normal aerial application techniques. The test was designed to evaluate the ability of the AutoCal I to keep up with ground speed changes while spraying and to evaluate the effect of spray initiation on controller error. The effect of spray initiation was evaluated by using 5, 10, 15, and 20 spray passes to spray the 23–ha (57–acre) plots. Each test run consisted of approximately 180–s total spray time divided among the number of passes required for that run. The test run was terminated when the target area, as determined by the Air–Star ‘acres’ display, had been sprayed. Four replicates of each treatment were applied in a randomized complete block design while maintaining a consistent application rate of 18.7 L/ha (2 gal/acre). Experimental error was determined by the difference between the actual volume of water sprayed on the area and the required volume, which was computed as the product of area sprayed and application rate. Theoretical controller error and a CR function time–constant, TC, were also computed to separate controller function error from experimental error.

The AutoCal II was only tested under dynamic application conditions. This test was similar to the plot sprays for the AutoCal I except that a range of application rates were used and the number of passes per plot remained constant for all treatments. Application rates used were 9.4, 18.7, 28.1, 37.4, 46.8, and 88.9 L/ha (1, 2, 3, 4, 5, and 9.5 gal/acre). Ground speed was purposely varied during each test run to evaluate the ability of the controller to track the changing flowrates due to changing speeds. Each test run was comprised of 10 spray passes of about 10–s duration. Application rates of 37.4 L/ha (4 gal/acre) or less had a swath width of 21.3 m (70 ft), but the 46.8 L/ha and 88.9 L/ha (5 and 9.5 gal/acre) rates had 18.3 m (60 ft) and 15.2 m (50 ft) swaths, respectively. Reductions in swath width reduced the area sprayed. Plot sizes were 12.9 ha (31.8 acres) for 21.3–m (70–ft) swaths, but the 18.3– and 15.2–m (60 and 50 ft) swaths covered only 11.0 and 9.2 ha (27.3 and 22.7 acres), respectively. Each test run was initiated with the spray system plumbing full of water and the hopper loaded with a volume of water equal to the expected volume to be sprayed plus about 76 L (20 gal) to maintain proper spray system operation at the end of the spray run. After spraying, the unsprayed water from the hopper was drained and weighed. The sprayed volume was then computed as the difference between the initial volume loaded and the unsprayed volume. The actual volume sprayed was then compared to the volume required (application rate × area sprayed) for the test run to evaluate experimental error. Theoretical error was computed for each spray run and the CR function was generated for evaluating the TC for error decay. Four replicates of each application rate were run to complete the study.

RESULTS AND DISCUSSION

AutoCal I performance under controlled conditions is presented in table 1. The results reflect the ability of the system to identify and apply the desired application rate. Ground speed during spray runs was maintained at 217 km/h (135 mph). Spray was initiated twice during each spray run, which covered about 11.6 ha (29 acres). All application rates were applied with the same calibration code and sensitivity settings. Experimental errors shown in table 1 were computed from the measurements of water volume sprayed during the run. The maximum experimental error was 1.55% and occurred while applying the 37.4 L/ha (4 gal/acre) application rate. Experimental errors ranged from 0.78 to 1.55% and were not statistically different at the 0.05 level of probability. The theoretical error was much smaller than the experimental error. It ranged from 0.3 to 0.8% and the smallest error occurred at the lowest application rate. Theoretical error revealed the response error of the controller and its ability to control the actual flowrate to the boom. Experimental error included errors in loading, collecting, and calibrating the flow sensor as well as the controller response.

The dynamic performance of the AutoCal I is summarized in table 2. The test treatments required the same number of hectares, but used different lengths of the spray run to evaluate the effect of turning the spray on and off. In effect, this compares the accuracy of the controller in spraying a long, narrow field to a short, wide field. All runs were made at the 18.7–L/ha (2–gal/acre) application rate. The maximum range in ground speed (difference between highest and lowest speed within a spray pass) that occurred while spraying replications of each treatment ranged from 35.4 km/h (22.0 mph) for the 15–pass treatment to 74.0 km/h (46.0 mph) for the 10–pass treatment. This level of speed variation is not consistent with normal application practice, but was used in the test to evaluate the ability of the flow controller to track dynamic variations in flow requirements. Error in this test increased with number of spray passes, as would be expected. Every time the spray was initiated, there was a short time interval required for the flowrate to settle down to the required value. Theoretical error showed a definite trend to increase as the number of passes increased. An error of 0.79% was observed for five passes and it increased to 3.2% for 20 passes. The experimental errors were slightly less than the theoretical errors in this study and were not statistically different. They had values ranging from 0.51 to 1.08% with the least value occurring for the five–pass treatment. Figure 4 shows a plot of required flowrate and actual flowrate versus time for a typical spray run made during this study. When spray was initiated, the actual flowrate increased from zero to 135–L/min (35.7–gal/min) with very little overshoot and followed the required flowrate throughout the run. Figure 5 is a plot of the theoretical error that occurred during the spray run plotted in figure 4. This error is the area between the required and actual flowrate curves. Error was based on the required flowrate; therefore, 'actual' flowrates that were smaller than the 'required' flowrate produced positive errors. The initial peak resulted from the large positive error that occurred as flowrate went from zero to the required value. It quickly decayed to near zero as the controller responded by adjusting the boom valve to the correct position. The rate of decay is indicative of how quick the controller responded to error. An error–decay time constant was computed that corresponded to the exponential waveform decay used to describe electronic signal decay. These values reflect the time required for the error magnitude to decay to a level that was 36.8% of its original amplitude. Time constants for the AutoCal I ranged from 0.28 to 0.32 s in this series of runs. These time constants show that error for the spray run was reduced to 36.8% of its total algebraic sum in about 0.3 s. Further evidence of the AutoCal I responsiveness can be observed in figure 6 where ground speed varied from 154 to 228 km/h (95.7 to 142 mph).

Table 1. Results of constant speed test on AutoCal I spray control system.[a]

Application Rate (L/ha)	Required Volume (L)	Theoretical Error (%)[b]	Experimental Error (%)
9.4	109	0.30 A	± 0.86 A
18.7	219	0.80 B	± 0.78 A
28.1	327	0.57 A B	± 0.78 A
37.4	436	0.65 B	± 1.55 A
$LSD_{0.05}$		0.29	1.45

[a] Test runs were comprised of two 45–s sprays at approximately 217 km/h (135 mph) covering 11.6 ha (28.6 acres). Calibration code was 218 and sensitivity was 9.

[b] Values followed by a common letter are not significantly different at the P = 0.05 level of probability as determined by LSD comparisons.

Conversion Factor: (L/ha)/9.354 = (gal/acre)

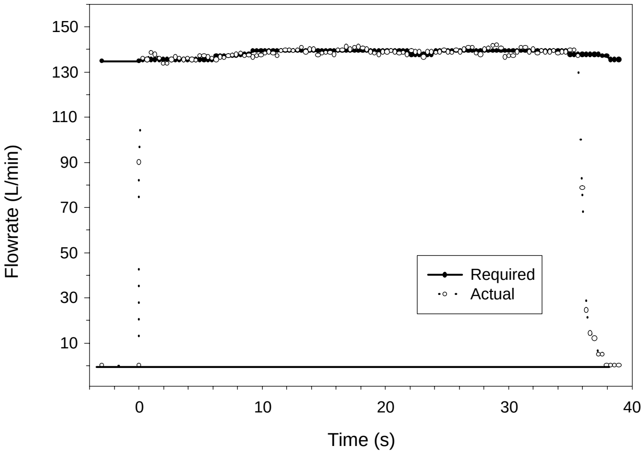

Figure 4. Required flowrate vs. actual flowrate for the AutoCal I while applying 19 L/ha (2 gal/acre) at a nominal speed of 217 km/h (135 mph). Conversion Factor: gal/min = (L/min)/3.785.

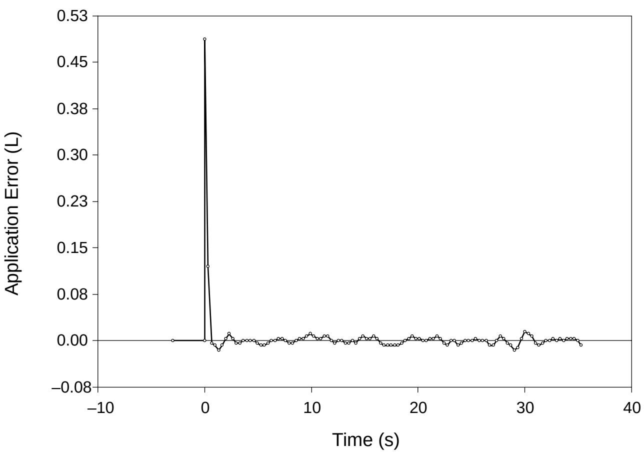

Figure 5. Theoretical error in volume applied for the spray application plotted in figure 3. Conversion factor: gal = (L)/3.785.

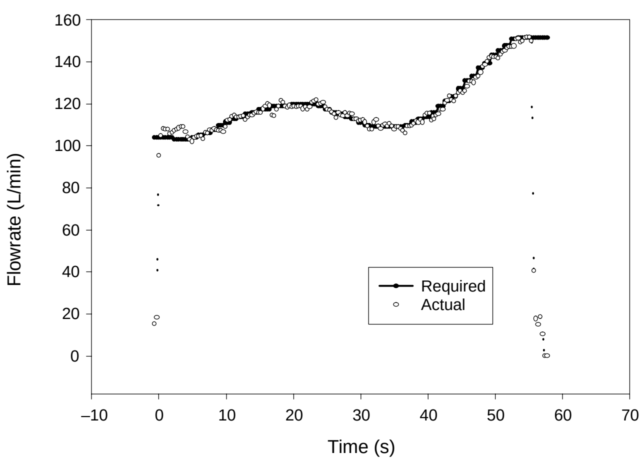

Figure 6. Response of the AutoCal I to extreme variations in ground speed. Speed ranged from 154 to 228 km/h (96 to 142 mph). Conversion Factor: gal/min = (L /min)/3.785.

Test results from the AutoCal II flow controller are presented in table 3. Experimental error ranged from 0.64 to 1.60% for the treatments tested. In this test, application rate was varied from 9.4 to 88.9 L/ha (1 to 9.5 gal/acre). Ten spray passes were used to perform the application on 12.9–ha (31.8–acre) plots for each treatment. Controller response was similar to that of the AutoCal I as shown by the error–decay time–constant values. No significant difference was observed between treatments for either experimental error or theoretical error. Theoretical error was larger than experimental error for this evaluation and this was not expected. Since experimental error includes that error associated with loading and unloading the plane as well as the theoretical error, one would expect the experimental error to be greater than theoretical error. A shift in a system parameter value, such as calibration code, could mask system error if the effect of the shift was to compensate for error in system performance. Statistical similarity among the treatments indicates that the application rate did not have a significant effect on system performance.

The results reported from this work reflect the performance achieved by the automatic flow control system after numerous evaluation–modification iterations between the author and manufacturer. Aerial applicators now have equipment available that provides a way to accurately apply agricultural chemicals with swath–to–swath consistency

Table 2. Performance of AutoCal I Automatic flow controller while spraying 23–ha (57–acre) plots of land.[a]

No. of Passes	Maximum Speed Range (km/h)[b]	Average Volume Required (L)	Theoretical-Error (%)[c]	Experimental Error (%)	Error Decay Time Constant (s)
5	38.6	457.5	0.79 A	± 0.51 A	0.28 A
10	74.0	412.6	1.65 A B	± 0.55 A	0.32 A
15	35.4	383.0	2.17 C B	± 1.08 A	0.27 A
20	48.3	435.1	3.20 C	± 0.97 A	0.30 A
$LSD_{0.05}$			1.14	1.37	0.11

[a] All applications were made at a rate of 19 L/ha (2 gal/acre). Calibration code was 214 and sensitivity was 8.
[b] Maximum Speed Range is the greatest difference between the maximum speed and minimum speed that occurred during any specific spray pass while applying a treatment. Conversion Factors: (L)/3.785 = (gal); (km/h)/1.609 = (mph).
[c] Values followed by a common letter are not different at the P = 0.05 level of probability as determined by LSD comparisons.

Table 3. Performance of the AutoCal II automatic flow control system while applying water at rates ranging from 9 to 89 L/ha.[a]

Application Rate (L/ha)	Maximum Speed Range (km/h)[b]	Average Volume Required (L)	Theoretical Error (%)[c]	Experimental Error (%)	Error Decay Time Constant (s)
9.4	12.9	120	3.65 A	± 0.64 A	0.27 A
18.7	16.1	245	2.31 A	± 0.95 A	0.22 A
28.1	19.3	365	4.59 A	± 0.69 A	0.44 B
37.4	14.5	482	3.12 A	± 1.60 A	0.32 A B
46.8	4.8	519	3.19 A	± 0.77 A	0.35 A B
88.9	33.8	854	4.75 A	± 1.03 A	0.44 B
$LSD_{0.05}$			2.67	1.26	0.14

[a] Each treatment application consisted of 10 spray passes with variable ground speeds. Calibration code was 205 and sensitivity was 10.
[b] Maximum Speed Range is the greatest difference between the maximum speed and minimum speed that occurred during any specific spray pass while applying a treatment. Conversion Factors: (L/ha)/9.354 = (gal/acre); (m) × 3.28 = (ft); (ha) × 2.471 = (acres); (L)/3.785 = (gal); (km/h)/1.609 = (mph).
[c] Values followed by a common letter are not different at the P = 0.05 level of probability as determined by LSD comparisons.

across the field, even if ground speed changes due to uncontrollable wind conditions.

SUMMARY

Test protocols were developed for evaluating the performance of automatic flow control systems for aerial applications. The evaluation included physical measurements of water volume sprayed and logged data that included parameters needed for computing required spray volume and describing all aspects of the controller function. Tests of the AutoCal I and AutoCal II automatic flow controllers have shown that both units are effective in maintaining accurate control of flowrate while performing aerial application jobs. During application runs the flowrate was corrected more than two times per second in order to track changing flow requirements due to changing speeds. The corrections were based on the difference between actual flowrate (from the flow meter) and the required flowrate computed from GPS ground speed, application rate, and swath width. The primary difference between the two controllers was that the AutoCal I controlled flowrate directly with the boom–valve and the AutoCal II controlled the flowrate indirectly with a bypass valve between the pump outlet and inlet. Tests with the AutoCal I showed that theoretical error in application control generally increased with application rate and number of passes required to perform the job. Average error for the AutoCal I ranged from 0.51 to 1.08% as the number of passes required to spray 23 ha (57 acres) ranged from 5 to 20. The AutoCal II did not exhibit similar trends with respect to application rate. Average error for the AutoCal II ranged from 0.64 to 1.60% as application rate ranged from 9.4 to 88.9 L/ha (1 to 9.5 gal/acre) while spraying 12.9 ha (31.8 acres) using 10 spray passes.

Aerial applicators now have equipment available that provides a way to accurately apply agricultural chemicals with swath–to–swath consistency across the field, even if ground speed changes due to uncontrollable wind conditions.

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